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PROPOSITION DE SUJET DE THèse

Intitulé : Méthode d'équilibrage harmonique pour la simulation des phénomènes aéroélastiques non-linéaires

Time-Spectral Method for non-linear aeroelasticity

Référence : **SNA-DAAA-2025-23**

(à rappeler dans toute correspondance)

Début de la thèse : 2025	**Date limite de candidature :** 2025

Mots clés : Aeroelasticity, Time-Spectral-Method (TSM), Numerical methods

Profil et compétences recherchés

Engineering School, or Master 2 in numerical methods, aerodynamic, mechanics or applied mathematics

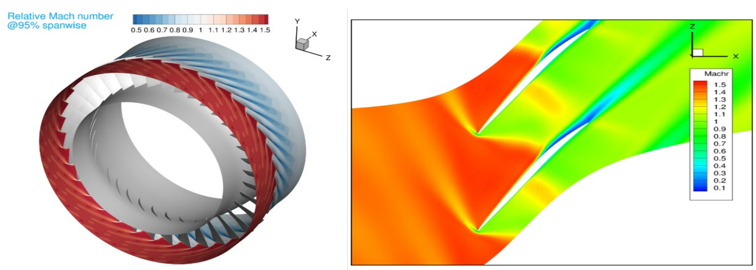
Good knowledge in CFD (Computational Fluid Dynamics), applied mathematics, numerical methods, and aerodynamics is required. Proficiency in Python/Fortran programming is necessary. Familiarity with aeroelasticity is appreciated.

Présentation du projet doctoral, contexte et objectif

The design of increasingly efficient aircraft while minimizing environmental impact requires the ability to simulate highly complex unsteady physical phenomena around these objects. The new trend put forth by industry leaders such as Safran and Airbus, featuring elongated blades or wings, demand a comprehensive modeling of nonlinear aeroelastic phenomena. To achieve this, fast, robust, and multiphysics-adapted numerical methods need to be developed within a high-performance computing context. The Aerodynamics, Aeroelasticity, and Acoustics Department (DAAA) of ONERA plays a major role in the development of these numerical methods, especially through the creation of new HPC codes for aeronautics.

In many scenarios, unsteady flows around aircraft and turbomachinery exhibit oscillatory behavior as they are influenced by periodic sources of excitation. Fan blades or compressor stages are naturally excited at the machinery's rotational frequency while disturbances caused by upstream wakes appear to be periodic in the frame of downstream blades. Moreover, the vibration of the structure induced by aeroelastic phenomena can add multiple sources of periodic excitation.

The conventional High-Fidelity methods currently used to simulate unsteady flows rely on time-stepping integration schemes. However, these methods become excessively expensive and probably inappropriate to time-periodic flows. In such cases, methods like the Time Spectral Method (TSM), which substitutes the time discretization by a spectral resolution in the Fourier space [1,2], are particularly suitable. If the number of harmonics required for flow modeling remains low, it is possible to achieve greater accuracy with significantly reduced computational time, while avoiding simulating the transient flow dynamics. This method is particularly valuable in turbomachinery [3,4], such as around fan and compressors blades.



3D Numerical simulation of compressor stage (Rotor 37)

Although the theoretical foundation of the method is now well-established, its enhancement and adaptability to increasingly complex problems are at the forefront of research activities in research institutes. In particular, ongoing work focuses on the numerical aspects of the method (stability, algebraic formulations, improvements of nonlinear solvers), high-performance computing (parallelization), and its extension to coupled physical problems (for instance fluid-structure interaction) [5].

The French institute ONERA, in collaboration with CERFACS, has developed a decade ago a Time Spectral Method (TSM) module in its CFD code elsA, enabling the resolution of unsteady periodic flow [6]. However, the current state of this module is limited in terms of applications and numerical performance. Although the elsA TSM solver can deal with many turbomachinery configurations, stability issues arise when a large number of harmonics are used. Second, TSM simulations can be computationally expensive in terms of CPU time and memory due to current limitations in the CFD solver's architecture.

As a result, our department has recently developed a modular TSM code prototype external to the elsA solver, allowing us to overcome the limitations of the CFD code architecture. This prototype is particularly valuable for testing new methodologies related to TSM, such as modern techniques for solving algebraic systems or coupling between fluid and structure. Currently, this module is not suitable for real flows (viscous or turbulent) or rotating flows encountered in turbomachinery.

The main objective of this thesis is to enhance the existing TSM prototype and apply it to Navier-Stokes equations in complex configurations encountered in the aeroelastic field. This will involve leveraging new linear algebra techniques and modern nonlinear Newton-Krylov algorithms. The thesis will hopefully conclude with a demonstration of the TSM method in a full aeroelastic simulation with strong coupling between the fluid and structure. Although the main developments will be focused on airfoil and plane aerodynamics, an application to turbomachinery flows is also aimed. Successfully reaching these objectives will unlock numerous opportunities in the field of optimization, design, and fundamental research related to aeroelastic phenomena.

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[2] A. Gopinath, A. Jameson, "Time Spectral Method for Periodic Unsteady Computations over Two- and Three-Dimensional Bodies", 43rd Aerospace Sciences Meeting and Exhibit, AIAA Paper 2005-1220, Reno, Nevada, Jan. 2005

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